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Analysis of the reliability of the components of a multiservice communication network based on the theory of fuzzy sets

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ABSTRACT

The article presents the results of modeling the solution to the problem of determining the reliability of the components of a multiservice communication network (MCN) based on the theory of fuzzy sets. The main characteristics of the equipment that affect the reliability parameters of the MCN are given. To solve the problem of determining the reliability of MCN components based on the theory of fuzzy sets, a multiservice network is presented in the form of a hierarchical diagram, which shows the main components of each network level. A multiservice network is presented as a parameter of the U function. The reliable state of the MCN depends on the state of the equipment at the corresponding levels. The results of modeling the solution to the problem of determining the reliability of MCN components based on the theory of fuzzy sets are presented using the mathematical apparatus of the theory of fuzzy sets and fuzzy logic in MATLAB fuzzy logic toolbox, fuzzyTECH.

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1. INTRODUCTION

In a multiservice network, heterogeneous information of various volumes with different intervals of their appearance is simultaneously processed. To ensure high-quality processing of a large amount of information, it is necessary to convert all information about the state and functioning modes of the multiservice communication network (MCN) components into a single form. Such a transformation can be carried out by presenting the entire volume of heterogeneous information in the form of membership functions [1], [2]. In view of the complexity of obtaining operational information for probabilistic models and the difficulties of operating with random variables, the use of the theory of fuzzy sets (TFS) for studying the reliability indicators of MCN becomes relevant. The use of TFS allows the coordination of various fuzzy solutions in the presence of fuzzy goals, restrictions, coefficients, initial and boundary conditions. TFS has the ability to carry out calculations not with a single point value, but with a characteristic function and obtain a fuzzy value as a result of calculations, for which a clear estimate can be obtained from the maximum value of the function. Guided by the above considerations, below is a methodology for allocating resources allocated to improve the reliability parameters of a multiservice network, based on the theory of fuzzy sets. Table 1 shows the main characteristics of the hardware and software used at the levels of a multiservice network [3], [4].

Table 1. Key equipment features affecting on the reliability parameters of the MCN

№	Type of equipment	Quantity	Average cost per unit	Mean K_G	Average workload
1	Gateways	N^g	C^g	$K_G{}^g$	Λ^g
2	Terminals	N^t	C^t	$K_G{}^t$	λ^t
3	IAD equipment	N^{IAD}	C^{IAD}	$K_G{}^{IAD}$	λ^{IAD}
4	DSLAM equipment	N^{DSLAM}	C^{DSLAM}	$K_G{}^{DSLAM}$	λ^{DSLAM}
5	MSAN equipment	N^{MSAN}	C^{MSAN}	$K_G{}^{MSAN}$	λ^{MSAN}
6	Switches	N^S	C^S	$K_G{}^S$	Λ^S
7	Routers	N^R	C^R	$K_G{}^R$	Λ^R
8	Channels of connection				
	1) access level	$N_d{}^{kc}$	$C_d{}^{kc}$	$K_{Gd}{}^{kc}$	$\lambda_d{}^{kc}$
	2) level of transport	$N_t{}^{kc}$	$C_t{}^{kc}$	$K_{Gt}{}^{kc}$	$\lambda_t{}^{kc}$
	3) level of services	$N_u{}^{kc}$	$C_u{}^{kc}$	$K_{Gu}{}^{kc}$	$\lambda_u{}^{kc}$
9	Computer equipment	N^{ko}	C^{ko}	$K_G{}^{ko}$	λ^{ko}
10	Software				
	1) access level	$N_d{}^{po}$	$C_d{}^{po}$	$K_{Gd}{}^{po}$	$\lambda_d{}^{po}$
	2) level of transport	$N_t{}^{po}$	$C_t{}^{po}$	$K_{Gt}{}^{po}$	$\lambda_t{}^{po}$
	3) level of services	$N_u{}^{po}$	$C_u{}^{po}$	$K_{Gu}{}^{po}$	$\lambda_u{}^{po}$

2. RESEARCH METHOD

As can be seen from the table (Table 1), each level of the MCN consists of a finite number of equipment of a certain type that perform the functions of this level. Each equipment characterized by reliable performance. During the operation of the MCN, various random disturbances can occur that directly affect the reliability parameters. As a result, of such a disturbance, failures in the operation of equipment may occur or equipment can function in "critical" conditions, that is, function on the "verge" of failure. The next factor is the different congestion of MCN sections at each level-some sections are over loaded with data streams, and some are weakly loaded. This ultimately leads to service applications with excessive delays or denial of service. As a result, the probability of losing applications due to untimely service or failure increases [5], [6].

When allocating the allocated resource to increase the reliability parameters of the MCN components, it is necessary to be guided by the statistical material obtained as a result of the functioning of the MCN for a certain time interval (for example, for a quarter or for six months) [7]-[9]. Based on statistical materials, you must perform the following operations: 1) determine the total value of the intervals for the uninterrupted operation of each equipment of the corresponding MCN level, that is, determine the total value of the MTBF ΣT_0 and the total equipment downtime ΣTp; 2) based on the data of paragraph (1), calculate the value of the availability coefficient of each equipment of a given level; 3) Average the K_G value over all equipment and calculate the average value of the K_G availability factor of the considered level; 4) perform operations 1, 2, 3 points for the levels of transport, management and services; 5) on the basis of an analysis of the equipment load at each level, determine "vulnerable points (communication channels, gateways, switches, digital subscriber line access multiplexer (DSLAM), multi-service access node (MSAN), integrated access device (IAD))", in which the intensity of requests and their average service time are relatively high; 6) as a result of the analysis, calculate the value of operator losses of the investigated multiservice network due to the unreliable functioning of its individual components. In other words, based on the results of processing statistical materials, it is necessary to determine the state of the investigated multiservice network [10].

The obtained statistical results are the basis for solving the problem of the allocation of the allocated resource for the purpose of increasing reliability between the components of the multiservice network levels [11], [12]. It is necessary to develop a scientifically grounded methodology for a comprehensive study of a multiservice communication network from the standpoint of the system analysis of its components and decision-making according to the selected criterion. Below, to implement this approach, it is proposed to use the methods of the theory of fuzzy sets (TFS), which allow to study the reliability indicators of a multiservice communication network from a systemic point of view under random disturbances (interference), violations of the reliability of individual elements or nodes, and short-term power outages.

3. PROBLEM DECISION

The multiservice network represented in the form of a hierarchical diagram as shown in Figure 1, which shows the main components of each network level. We represent the multiservice network as a parameter of the function U. In Figure. 1, the following designations are adopted: U - a multiservice network that provides various types of services; U_1- access level; U_2 - transport layer; U_3- control level; U_4- level of service [13]-[15].

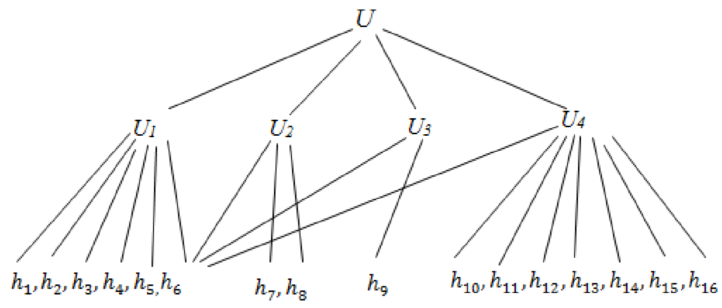

Figure 1. Hierarchical diagram of multiservice network

3.1. Hierarchical diagram of multiservice network

When performing the request, in general, all levels take part, that is, equipment at the MCN levels are interconnected.

$$U_1 \leftrightarrow U_2 \leftrightarrow U_3 \leftrightarrow U_4$$

The reliability of the MCN depends on the condition of the equipment at the appropriate levels; it can be represented as follows: U(U_1,U_2, U_3, U_4)=$\alpha_1 U_1(h_1, h_2, h_3, h_4, h_5, h_6) + \alpha_2 U_2(h_6, h_7, h_8) + \alpha_3 U_3(h_6, h_9) + \alpha_4 U_4(h_6, h_{10}, h_{11}, h_{12} h_{13}, h_{14}, h_{15}, h_{16})$. $U_1(h_1, h_2, h_3, h_4)$-access level; h_n-is a parameter that determines the amount of equipment needed; h_1-gateways (quantity); h_2-terminals; h_3-IAD equipment; h_4-DSLAM equipment; h_5-MSAN equipment; h_6-communication channels. $U_2(h_7, h_8, h_9)$-transport layer; h_7-communication channels of the transport layer; h_8-switches; h_9-routers. $U_3(h_{10}, h_{11})$-control level; h_{10}-control level communication channels; h_{11}-software switch Softswitch. $U_4\big(h_{12}\, h_{13}, h_{14}, h_{15,} h_{16}, h_{17}, h_{18}, h_{19}\big)$ -level of service; h_{12}-communication channels of the service level; h_{13}-application servers; h_{14}-database servers; h_{15}-file servers; h_{16}-"wireless" server; h_{17}-proxy servers; h_{18}-mail servers; h_{19}-DHCP servers. a_1, a_2, a_3, a_4-weighting factors characterizing the state of reliability of the corresponding level, and $a_1 + a_2 + a_3 + a_4 = 1$. Next, the main factors affecting the stability of the functioning of the MCN are determined [3]. The main factors influencing the structural stability of the MCN are divided into: external, internal, engineering and service factors.

The article [3] describes the decision-making method for ensuring the reliability of the MCN, which is based on the theory of fuzzy sets. The factors affecting the stability of the functioning of the MCN are characterized by heterogeneity and have a different scale of measurements (in terms of quantity and quality). Therefore, the task of making decisions (MD) to ensure the stability of the functioning of the MCN is reduced to the sequential solution of the following interrelated tasks: 1) identification of the state of the MCN (carried out on the basis of a system analysis of the main factors affecting the stability of the MCN); 2) ranking of the states of the MCN; 3) determination of decision-making criteria. The implementation of the first paragraph of the PR is carried out by setting up a complex MCN model based on the integration of the principles of the theory of fuzzy sets (TFS). For this, the state of the MCN is represented as a functional dependence on the relevant factors:

$$\mathrm{U} = \mathrm{f}_U(\mathrm{U}_1, \mathrm{U}_2, \mathrm{U}_3, \mathrm{U}_4), \quad (1)$$

$$\mathrm{U}_1 = \mathrm{f}_{\mathrm{U}_1}(\mathrm{x}), \quad (2)$$

$$\mathrm{U}_2 = \mathrm{f}_{\mathrm{U}_2}(\mathrm{y}), \quad (3)$$

$$\mathrm{U}_3 = \mathrm{f}_{\mathrm{U}_3}(\mathrm{z}), \quad (4)$$

$$U_4 = f_{U_4}(p), \quad (5)$$

Here x, y, z are the influence of external, internal and engineering factors, p is the service factor [4]. The assessment of the stability of the functioning of the MCN based on the complex model (1) is implemented by designing the information model of the MCN, based on the information unit for each point (gateway, communication channel, multiplexing equipment) and presented in the form of an information matrix:

$A^U = (a_{ij}), i = \overline{1,n;}\ \ j = \overline{1,m,}.$

Elements a_{ij} of the matrix are formed according to the following principle:

$$A = (a_{ij}), a_{ij} = i_1 i_2 i_3 i_4 i_5 i_6 i_7 i_8 i_9 \quad (6)$$

i_1-access network equipment, i_1=1-different terminals, i_1=2-different gateway equipment, i_1=3-IAD equipment, i_1=4-DSLAM equipment, i_1=5-MSAN equipment, i_1=6-layer communication channels access. i_2-transport layer equipment, i_2=1-transport layer communication channels, i_2=2-layer 3 switch equipment, i_2=3-router equipment. control level, i_3 control level equipment, i_3=1-control level communication channels; i_3=2-Softswitch hardware, i_4 -equipment of the service level, i_4=1-communication channels of the level of service, i_4=2-equipment of application servers, i_4=3-equipment of database servers, i_4=4-file servers, i_4=5-"wireless" server, i_4=6-proxy servers, i_4=7-DHCP servers. $i_5 = 1 \div 3$-the degree of influence of factors, i_5=1-BN (below the norm), i_5=2-N (normal), i_5=3-AN (above the norm). i_6-external factors, i_7-internal factors, i_8- engineering factors, i_9-service factor. The initial values of the parameters $i_1 - i_4$-are determined based on the MCN topology, and $i_5 - i_9$-are determined on the basis of appropriate calculations, modeling, and expert assessments.

Further, on the basis of such information, a set of possible situations $U = (x_{ij}^N,\ y_{ij}^N,\ z_{ij}^N,\ p_{ij}^N)$, is formed, on the basis of which the information model is formed in matrix form. Here $x_{ij}^N,\ y_{ij}^N,\ z_{ij}^N,\ p_{ij}^N$ are the permissible values of external, internal, engineering factors and service factors. A set of possible situations U_{ij}^B is formed by introducing the so-called "term", that is, introducing sets of the type BN, N, AN, meaning <below normal>, <normal>, <above normal>. This approach will make it possible to single out many typical situations (U^T), from the set of possible situations (U^B), i.e. $U^T \subset U^B$, card (U^T) ≪card (U^B). The set of typical situations describes quite fully the possible states of the MCN objects, taking into account the uncertain factors affecting the stability of the MCN functioning. Thus, it can be stated that a limited set of fuzzy (typical) situations can describe an almost infinite number of states of the MCN components [16]. Based on the situational analysis, the decision process to determine the option that ensures the stable operation of the MCN can be presented in the following sequence: 1) many possible situations are formed (U^B); 2) a set of typical situations (U^T) is determined, the input situation (U^B) for a specific MCN component (communication channel and gateway), is compared with typical situations from U^T stored in the database and the output fuzzy situation is determined; 3) based on the analysis of the output fuzzy situation, a solution necessary for this situation is determined.

Moreover, for the formal description of fuzzy situations, constructions of the form are used:

$$< \Delta\widetilde{S}, R, \widetilde{C_{(\iota)}} >, \quad (7)$$

where, $\Delta\tilde{S} = \begin{pmatrix} \Delta\tilde{x} \\ \Delta\tilde{y} \\ \Delta\tilde{z} \\ \Delta\tilde{p} \end{pmatrix}$, $R = \begin{pmatrix} x \\ y \\ z \\ p \end{pmatrix}$, $\widetilde{C_{(\iota)}} = \begin{pmatrix} \widetilde{C_{(1)}} \\ \widetilde{C_{(2)}} \\ \widetilde{C_{(3)}} \\ \widetilde{C_{(4)}} \end{pmatrix}$

$\Delta\widetilde{S}$- linguistic estimates of the factors taken into account; R – fuzzy results (universes) by factors; $\widetilde{C_{(\iota)}}$-membership functions of changes in factors, defined as follows:

$$\widetilde{C_{(\iota)}} = \left\{< \frac{\alpha_i}{T_1^i} >, < \frac{\beta_i}{T_2^i} >, < \frac{\gamma_i}{T_3^i} >\right\}, \quad (8)$$

where, T_1^i, T_2^i, T_3^i, -are linguistic estimates of changes in the *i*-factor corresponding to specific elements of the set {BN, N, AN}.

The fuzzy information processing subsystem receives fuzzified (approximate, fuzzy) information about changes in factors (*x*, *y*, *z* and *p*), checks the MCN for violations of the functioning norms, carries out diagnostics of the state, i.e. according to model (1) determines fuzzy estimates of the states U_1, U_2, U_3, U_4, i.e. $\mu(U_1)$, $\mu(U_2)$, $\mu(U_3)$, $\mu(U_4)$. The decisions made, depending on the state (situation) of the MCN, can be of a preventive, prophylactic, localization or restorative nature.

3.2. Justification

At the next stage, the issues of choosing a control solution and its justification are solved. At the same time, in relation to the decisions (alternatives) made, the following designations are introduced:

A_S - $<set\ of\ possible\ solutions>$; A_D - $<set\ of\ feasible\ solutions\ from\ possible\ ones>$; $A_S^P - <set\ of\ solutions\ of\ a\ preventive\ nature\ (P)>$; $A_S^{PS} - <set\ of\ preventive\ solutions\ (PS)>$; $A_S^L - <set\ of\ solutions\ of\ a\ localization\ nature\ (LS)>$. $A_S^{RN} - <set\ of\ solutions\ of\ a\ restorative\ nature\ (RN)$.

It is clear that $A_D \subset A_S$, $A_S = A_S^P \cup A_S^{PS} \cup A_S^L \cup A_S^{RN}$ (9)

It is expedient to represent the set A_S in the form of a matrix $A=(a_{ij})$.

The element $a_{ij} \in A$ means the choice of a solution corresponding to the *i*-factor, for example $a_{3,4}$-the choice of a solution of a restorative nature in accordance with engineering factors (short-term or emergency shutdown, and choice of energy types). The choice of a specific solution is based on the selected evaluation criterion [17]-[20]. In the work, as a decision-making criterion, a criterion is used that ensures the required reliability of the MCN at the minimum value of the functional (4). It should be noted that the formation of sets of possible, admissible in a particular situation, alternatives (A_S, A_D), as well as decision-making (preventive, preventive, localization or restorative) has a rather complex character and is carried out on the basis of generalized assessments of the influence of factors on the stability of the MCN functioning.

3.3. The formation of the source data statistical data

The choice of the best alternative solution ($A_S^P, A_S^{PS}, A_S^L, A_S^{RN}$) is carried out on the basis of a fuzzy-multiple analysis of the MCN information model formed on the basis of the results of the fuzzy-logical model and many typical situations [21], [22]. The management system (or expert) that makes the decision takes into account the following possible consequences of the influence of the factor on the stability of the MCN functioning, that is, on the degree: 1) deterioration in the quality of the transmitted information; 2) reducing the amount of information transmitted; 3) occurrence of short-term and long-term interruptions in data transmission systems, distortion of the content of transmitted information as shown in Table 2. Table 2 shows the statistics that are used in the simulation. The results of modeling using the mathematical apparatus of the theory of fuzzy sets and fuzzy logic in the environment MATLAB fuzzy logic toolbox, fuzzyTECH [23]-[25].

Table 2. Statistical data

Parameters		Universum of Inequality Limits of values	
x_1 - gateways (capacity)	[100…500] ports	[500…1000] ports	[1000…3000] ports
x_2 –terminals (cost)	[5…100] conventional units	[10…40] conventional units	[50…100] conventional units
S_1 reliability level	[0.8.....0.94]	[0.95.....0.97]	[0.97.....0.98]
x_7–Switches (performance)	[500000÷ 1 mill.] packets/s	[1 mill.÷ 10 mill.] packets/s	[10 mill.÷ 50 mill.] packets/s
x_8– Routers (performance)	[1 mill.÷ 10 mill.] packets/s	[10 mill.÷100 mill.] packets/s	[100 mill.÷1 bill.] packets/s
S_2	[0.86.....0.95]	[0.95.....0.98]	[0.98.....0.99]
x_9– Softswitch 1 software switch (performance)	[10 mill..÷ 100 mill.] calls/hour	[100 mill..÷ 1 bill.] calls/hour	[1 bill.÷ 10 bill.] calls/hour
x_9–Softswitch 2 software switch (performance)	[10 mill..÷ 100 mill.] calls/hour	[100 mill..÷ 1 bill.] calls/hour	[1 bill.÷ 10 bill.] calls/hour
S_3	[0.95.....0.96]	[0.96.....0.98]	[0.989.....0.999]
x_{10} - application servers (processor performance)	[6…8] nuclear	[8…10] nuclear	[10…15] nuclear
x_{11} - database servers	[8…10] nuclear	[10…15] nuclear	[15…20] nuclear
S_4	[0.97.....0.98]	[0.98.....0.99]	[0.999.....0.9999]

4. RESULTS AND ANALYSIS

Simulation results with using of mathematical apparatus of the theory of fuzzy sets and fuzzy logic in the MATLAB environment fuzzy logic toolbox, fuzzyTECH. The results of modeling each level of a multiservice network using the mathematical apparatus of the theory of fuzzy sets and fuzzy logic in MATLAB fuzzy logic toolbox, fuzzyTECH showed the concavity of functions that characterize the main parameters of reliability and quality indicators of the services provided. For each level, basic statistics are entered in the software environment (Figure 2) and results are obtained in the form of concave functions (Figures 3-6).

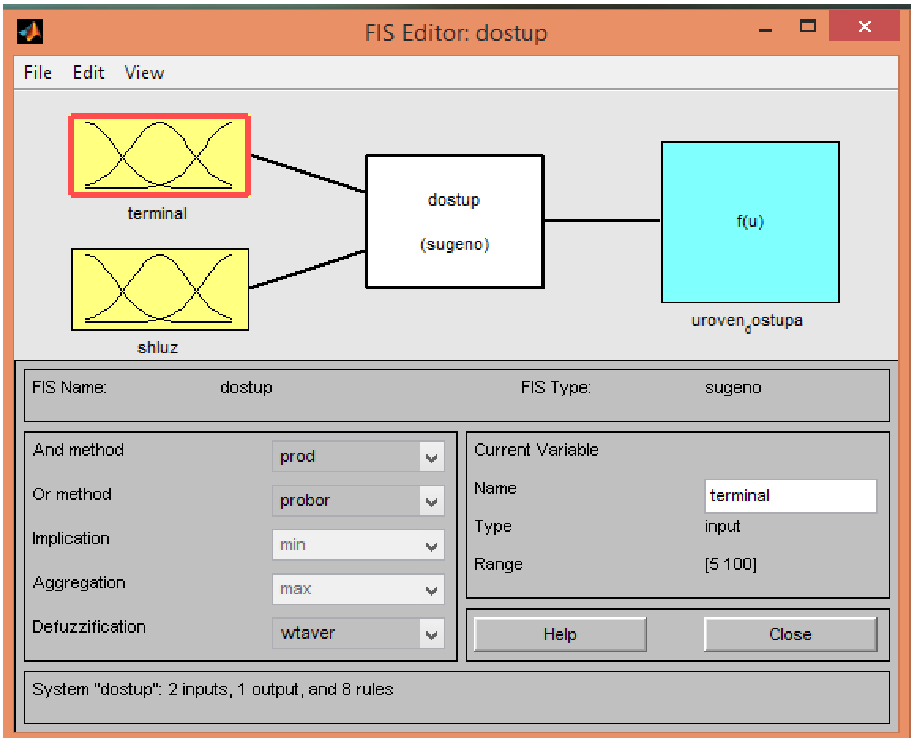

Figure 2. Entering master data at the access level

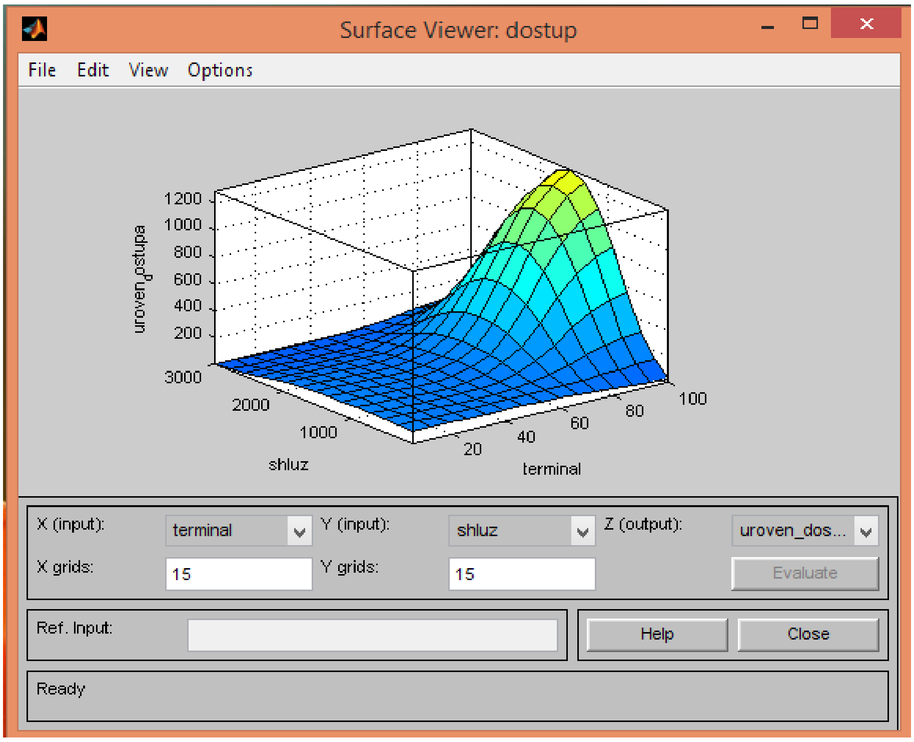

Figure 3. Simulation result of access level

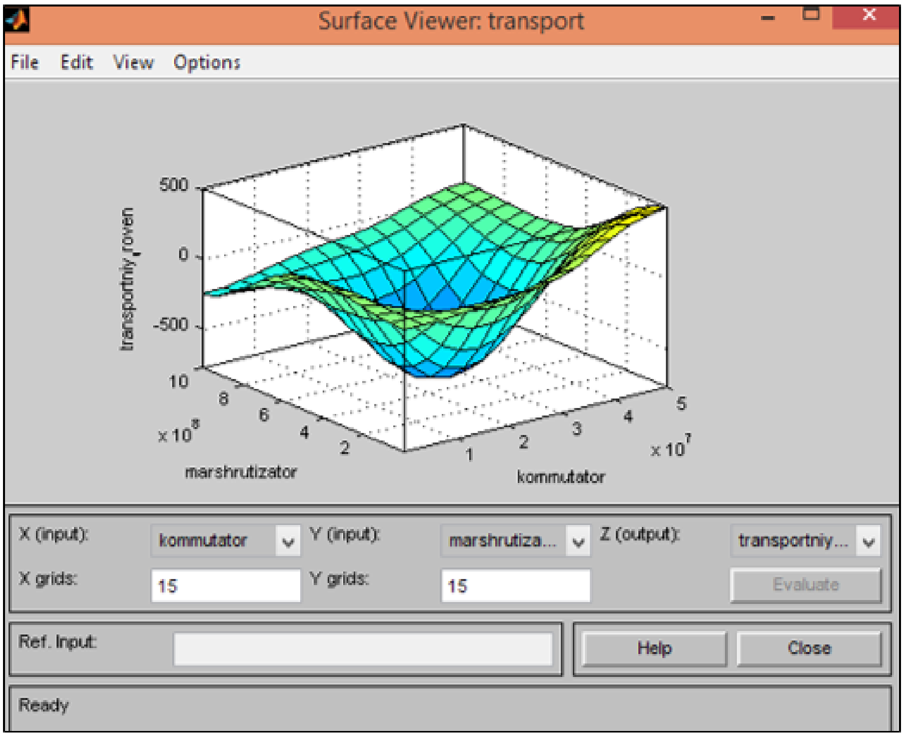

Figure 4. Simulation result of transport level

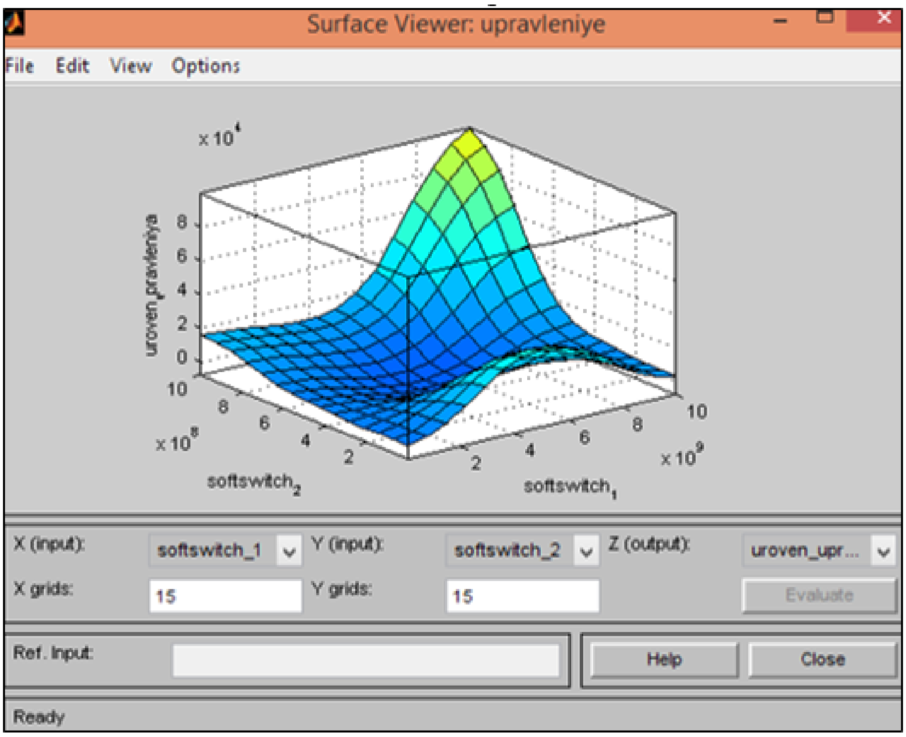

Figure 5. Simulation result of management level

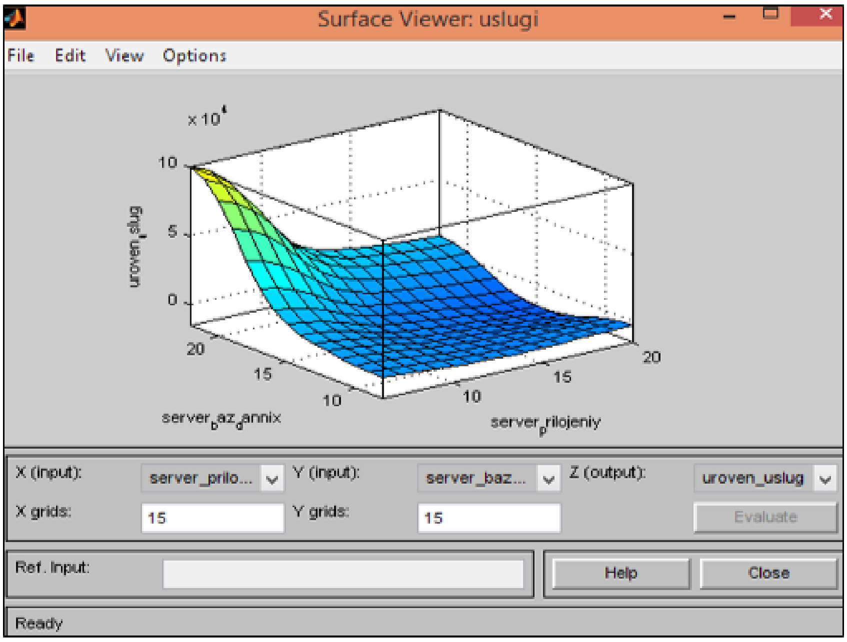

Figure 6. Simulation result of service level

5. CONCLUSION

The results of the analysis of the reliability of MCN components showed that the choice of the best alternative solution ($A_S^P, A_S^{PS}, A_S^L, A_S^{RN}$) is carried out on the basis of a fuzzy-multiple analysis of the information model of the MCN formed on the basis of the results of the fuzzy-logical model and many typical situations. The decision made by the expert (control system) takes into account the possible consequences of the influence of one factor or another on the stability of the MCN operation. When choosing the best alternatives, that is, decision making options for each type of factor, the system proceeds from the criterion: ensuring the required reliability at given costs. In the work, the choice of a rational alternative is proposed to be carried out on the basis of the method of non-dominant alternatives S. A. Orlovsky, based on the aggregation (processing) of fuzzy information characterizing the relationship between alternatives according to the selected criterion or several criteria. The proposed method made it possible to analyze and obtain simulation results by solving the problem of determining the reliability indicators of a multiservice communication network. The adoption of alternative solutions in order to improve the reliability of energy factors is considered. In further research, the authors will analyze the main parameters of the quality of service of a multiservice communication network using the mathematical apparatus of the theory of fuzzy sets and fuzzy logic.

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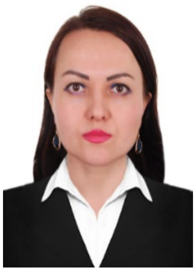

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